SILVA BALCANICA

Silva Balcanica 25(2): 101-112 (2024)
doi: 10.3897/silvabalcanica.25.e121324

RESEARCH ARTICLE

Changes in erosion susceptibility of a Chromic Haplustert pasture soil by some polymers under simulated rainfall

Tugrul Yakupoglu[1], Nutullah Ozdemir[2]

[1]*Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Yozgat Bozok University, 66900, Yozgat, Türkiye*
[2]*Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Ondokuz Mayis University, 55200, Atakum, Samsun, Türkiye*

Corresponding author: Tugrul Yakupoglu (tugrulyakupoglu@hotmail.com)

Academic editor: Miglena Zhiyanski | Received 24 February 2024 | Accepted 03 June 2024 | Published 06 August 2024

Citation: Yakupoglu T., Ozdemir N. 2024. Changes in erosion susceptibility of a chromic haplustert pasture soil by some polymers under simulated rainfall. Silva Balcanica 25(2): 101-112. https://doi.org/10.3897/silvabalcanica.25.e121324

Abstract

Due to the climate change that has become evident especially in the last ten years, ecosystems such as forests and pastures in the Mediterranean climate zone have become even more vulnerable to degradation. High erosive precipitation increases the amount of erosion in these soils with increasing their erodibility. The aim of this study was to determine to what extent some polymers, such as polyacrylamide and polyvinylalcohol, can prevent runoff and soil loss from erosion pans where a pasture soil was placed. For this purpose, aggregates of soil samples <8 mm from the A horizon of a Chromic Haplustert were used. Polyacrylamide and polyvinylalcohol solutions at different doses (0, 3.5, 7.0 and 14.0 kg ha^{-1}) were applied to the aggregates by spraying. Erosion pans with slopes of 9% and 15% were exposed to simulated rainfall produced by a drop former rainfall simulator for one hour. The simulation trial was planned as 2 replications according to the randomized plots trial design. During simulated rainfall, runoff water and sediment from pans were collected at 10-minute intervals. Transported soils were expressed as dry weight, and runoff waters were expressed as volumetric. According to the results obtained, the highest runoff occurred from a 15% inclined soil pan (11.06 mm) without polymer applied (control). After one hour of simulated rainfall, runoff did not occur from some pans with high-doses of applied polymer. The amount of soil transported from the control pan by runoff and by splashing to the sides is 362 and 4241 kg ha^{-1}, respectively. The pan, in which the least soil is carried by splashing, was the one with a 9% slope and the highest dose of polyacrylamide (97 kg ha^{-1}). Statistical results show that polyvinylalcohol was

more successful than polyacrylamide in reducing soil and water losses especially on 15% slope. These results indicate that the application of polymer to pasture soils can be a valid way to combat erosion, but the treatments should be carried out by choosing the right dose, taking into account factors such as the slope of the land, the erodibility of the soil and the erosivity of rainfall.

Key words
polyacrylamide, polyvinylalcohol, rainfall erosivity, soil erodibility, soil management

Introduction

Land and soil degradation is one of the biggest problems threatening the balance of ecosystems and sustainable agricultural activity. Sustainable agricultural production is required to meet the increasing demand for food. The increase in food demand in parallel with population growth and the needs of the developing industry increase the demand for land. In order to meet these demands, it is necessary to increase the yield obtained from the unit area and to ensure the sustainability of existing soil resources. For this purpose, it is necessary to take protection measures against factors that cause soil degradation and reduce yields or cause soils to disappear. Accelerated soil erosion, especially in areas with a sloping land structure or poor cover, is triggered by use and damages the economies of countries by reducing soil productivity (Evin et al. 2004). As in the rest of the world, erosion is one of the most important ecological problems threatening the natural resources of Türkiye (Doğan et al. 2000).

In order to take effective measures against erosion, it is necessary to know the factors that prepare it and accelerate or slow it down by affecting it in different degrees, to determine their functions and to determine the methods of minimizing the negative effects or contributions of these factors. The phenomenon of erosion is related to the erosion-forming power of climate and the erodibility of soil. Other factors (topography, vegetation and human impacts) affect the extent and direction of erosion. Rainfall is the main component of climate that directly affects water erosion. Rainfall-induced water erosion is mechanistically classified into four categories: (1) raindrop fragmentation and transport by raindrop splashing, (2) raindrop fragmentation and transport by raindrop splashing of surface runoff water, (3) raindrop fragmentation and transport by surface runoff, and (4) surface runoff fragmentation and transport by surface runoff (Kinnell, 2005).

Measuring surface runoff under natural conditions is time consuming and expensive. Therefore, there is a need for methods that can provide results in a short time. To this end, researchers have focused on rainfall simulators that can be successfully used in soil conservation studies (Köse and Taysun, 2000; Şahin and Alagöz, 2000). Operability under controllable conditions and repeatability of experiments in short time periods are the most important benefits. The use of sprinklers provides numerous conveniences and possibilities in data acquisition and therefore different aspects of erosion can be investigated rapidly. Especially since the 1980s, raindrop studies have

improved the understanding of the mechanisms of soil splash erosion (Nearing et al. 1986; Erpul and Çanga, 2001) and have largely characterized the intrinsic resistance of soil to erosion (Sharma et al. 1991). These studies reveal the inevitability and necessity of using rainfall simulators in erosion studies.

For many years, many studies on soil erosion have been conducted and are still being conducted. Researchers have tried many ways to increase the structural strength of soils. For this purpose, the use of polymers as soil conditioners is popular. These conditioners, which are high molecular weight organic polymers or inorganic salts, have hydrophilic or hydrophobic properties according to their water solubility (Yolcu, 2001). Polyvinylalcohol (PVA) and polyacrylamide (PAM) are two of the synthetic stabilizers that can be used as soil conditioners (Aksakal and Öztaş, 2004a). Many researchers (Sojka et al. 1998; Green et al. 2000; Aksakal and Öztaş, 2004b) have investigated the effect of PVA and PAM on the physical properties of soils and reported that these synthetic polymers provide high infiltration rates during rainfall, reduce surface runoff, improve soil physical properties and thus increase soil resistance to erosion.

The aim of this study was to investigate the effects of PVA and PAM applied at different doses to a Vertisol pasture soil on runoff and soil losses using simulated rainfalls under laboratory conditions.

Material and method

Soil and land properties

The soils used in the polymer application trial were taken from the Golet Basin within the borders of Samsun province. This soil is located in the Vertisol taxonomic order due to the fact that the amount of clays with swelling-shrinkage properties is very high throughout the profile, it has deep and wide cracks in the summer season, especially in August, and slickensides (ss) are observed between 19-65 cm, in the Ustrert sub-order and Haplustert large group due to its moisture regime, and in the Chromic Haplustrert sub-group due to its chroma 3. General land and profile views are given in Figure 1. The potential distribution of the studied soil class is widespread for the pastures of this catchment. Some chemical and physical analysis results of the soil are given in Table 1.

Most of the uplands in the basin of the pond were formed from the Eocene of Time III and the lands on the slope foothills were formed from the Upper Cretaceous phyllite of Time II (Kara et al. 1993). Most of the natural vegetation of the basin consists of oak trees. The remaining part of the land consists of natural pastures and meadows. Shrub vegetation is also common. In addition, tree and shrub species such as plane tree, willow, poplar, tamarisk are observed in the basin. In the agricultural areas where shrub vegetation has been destroyed and previously cultivated but now abandoned, meadow vegetation is dominant (Özen, 1988). The annual precipitation in the pond basin is 670.2 mm, the maximum precipitation falls

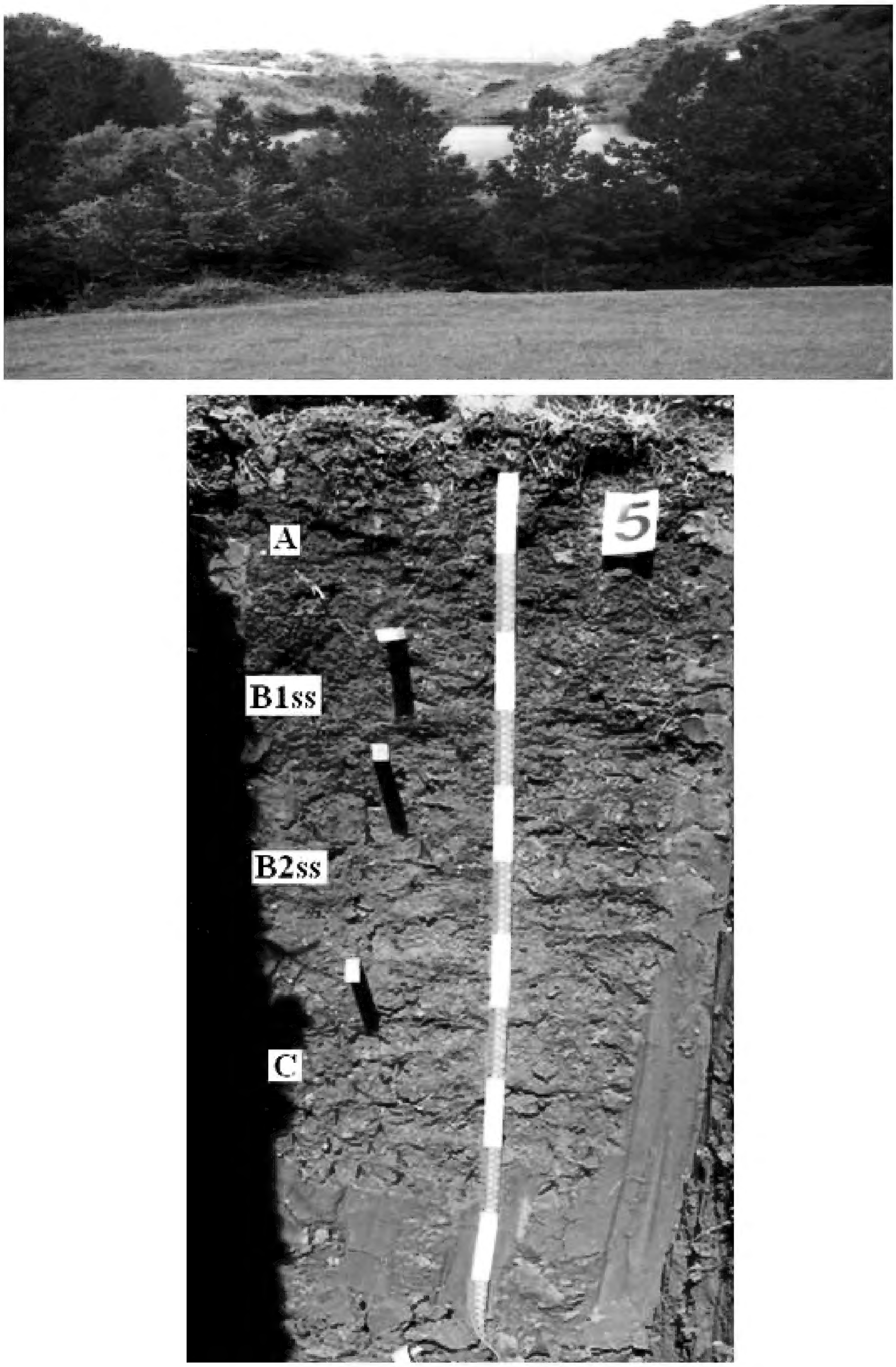

Figure 1. General land and profile views of the Chromic Haplustert

in October with 87.4 mm and the minimum precipitation falls in July with 31.3 mm. The hottest months are July and August (23.2 °C) and the coldest month is February (6.6 °C). The climate of the pond basin has Eastern Black Sea climate characteristics. Summers are hot and partially rainy, while winters are cool and rainy. The soil temperature regime of the research area was defined as Mesic and soil moisture regime as Ustic (Yakupoglu, 2010).

Table 1. Some chemical and physical properties of the Chromic Haplustert

Horizon	Depth (cm)	pH*	EC* (dS m^{-1})	Salt (%)	$CaCO_3$ (%)	SOM (%)	Colour (dry, wet)
A	0-19	7.66	0.691	0.032	8.78	2.72	2.5 Y 4/3 2.5 Y 3/2
B1ss	19-39	7.95	0.581	0.026	12.58	1.18	2.5 Y 4/2 2.5 Y 3/2
B2ss	39-65	7.94	0.523	0.024	10.73	0.62	2.5 Y 5/3 2.5 Y 4/3
C	65+	8.0	0.571	0.026	11.75	0.56	2.5 Y 5/4 2.5 Y 4/4
Horizon	Sand	Silt	Clay	Textural class	HC (cm h^{-1})	FC (%)	PWP (%)
A	10.93	16.16	72.91	C	2.44	44.0	28.8
B1ss	11.07	18.41	70.52	C	1.71	41.7	26.5
B2ss	11.78	16.10	72.12	C	2.48	43.5	24.9
C	14.15	18.14	67.71	C	2.30	43.3	26.2

*pH and EC values were measured in saturation paste. EC: electrical conductivity, SOM: soil organic matter content, HC: hydraulic conductivity, FC: field capacity, PWP: permanent wilting point

Polymers

Polyvinyl alcohol (PAM) and polyacrylamide (PVA) were used as soil conditioners. Among the synthetic polymers used, PAM ($(-CH_2CHCONH_2-)_n$) is a linearly bonded, water-soluble acrylamide sodium acrylate copolymer and PVA ($(-CH2OHOH-)_n$) is a cross-linked venylalcohol-acrylic acid that is hydrophobic up to a certain solvent temperature. These two soil conditioners are widely used in agricultural studies (Aslan, 2004). The molecular weights of PAM and PVA applied to the soils under investigation were 200000 g and 72000 g, respectively.

Experimental

Disturbed surface (0-15 cm) soil samples were taken from the to represent the Chromic Haplustert. These soil samples were dried under atmospheric conditions and then pounded with a wooden mallet and passed through an 8 mm sieve to be placed in soil pans. Sea sand was placed in the first 10 cm of the pans with dimensions of 30 x 29.5 x 15 cm (length-width-depth) and the drainage holes in the bottom were covered with coarse filter paper. After the surface of the sand was carefully leveled, a cheesecloth was laid over it and the remaining 5 cm of the pan was leveled by placing samples sieved through an 8 mm sieve, taking into account the runoff initiation level. It was determined that the volume weights of the soils stacked in the erosion pans ranged between 1.09-1.18 g cm^{-3} (±0.046). Approximately 4.9 kilos of soil was packed into each pan.

PAM and PVA were applied to the prepared erosion pans in 500 ml solutions at four different doses (0, 3.5, 7.0 and 14.0 kg ha^{-1}) including control. The pans were prepared 1 night before sprinkling. During the 60-min rainfall simulation period, rainfall with an intensity of 70 ± 5 mm h^{-1} and a kinetic energy of approximately 27.95 J m^{-2}-mm with a C_V value of 0.87 was rained on the pans. A laboratory-type simulator, modified from Erpul and Çanga (2001), was used to generate simulated rainfall. This simulator is technically described in another paper (Yakupoglu et al. 2018). With the start of runoff, sediment and water samples were taken at 10 minute intervals with aluminum containers placed under the discharge opening of the soil pan. The aluminum containers in which the runoff and sediments were collected were left for 1 night for settling and when the runoff water became clear, it was transferred to a glass tape measure by siphoning. To determine the amount of soil moving by side splash, splash-boards were placed on both sides of the soil pan at a distance of 6 cm from the pan. These splash-boards, which have dimensions of 140 x 120 cm and are made of metal material, have a sloping groove at the bottom. Soil particles on the splash-boards were washed into the gutter every 10 minutes from the beginning of the rainfall and samples were collected with plastic containers placed at the mouth of the gutter. The material in these plastic collectors was then transferred to aluminum containers. Twice the amount of material collected by the splash plates was considered as the total amount of soil splashed (Moore and Singer, 1990). After the runoff amount was determined, the soils in the aluminum containers were dried at 105°C, weighed and recorded to calculate the amount of soil lost through runoff and splashing (Yönter and Geren, 2006). Some views from the rainfall simulation experiment were given in Figure 2.

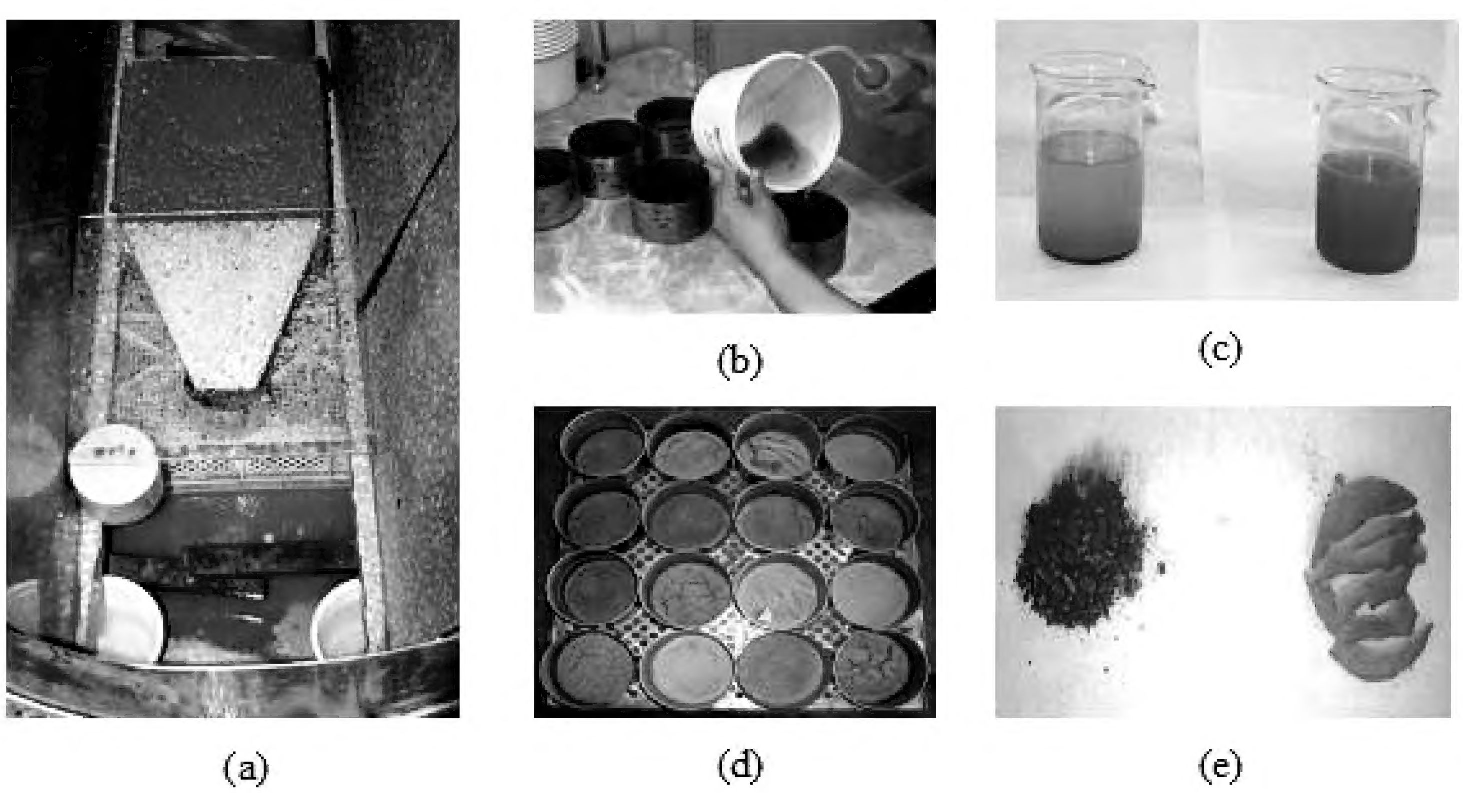

Figure 2. Views from the rainfall simulation experiment (a: view of the soil pan during simulated rainfall application; b: transfer of soil carried by splashing to aluminum containers; c: view of different runoff water carrying sediment; d: pictures of dry soil in the oven; e: oven-dry view of soil transported by splashing (in the left) and suspended by runoff (in the right).

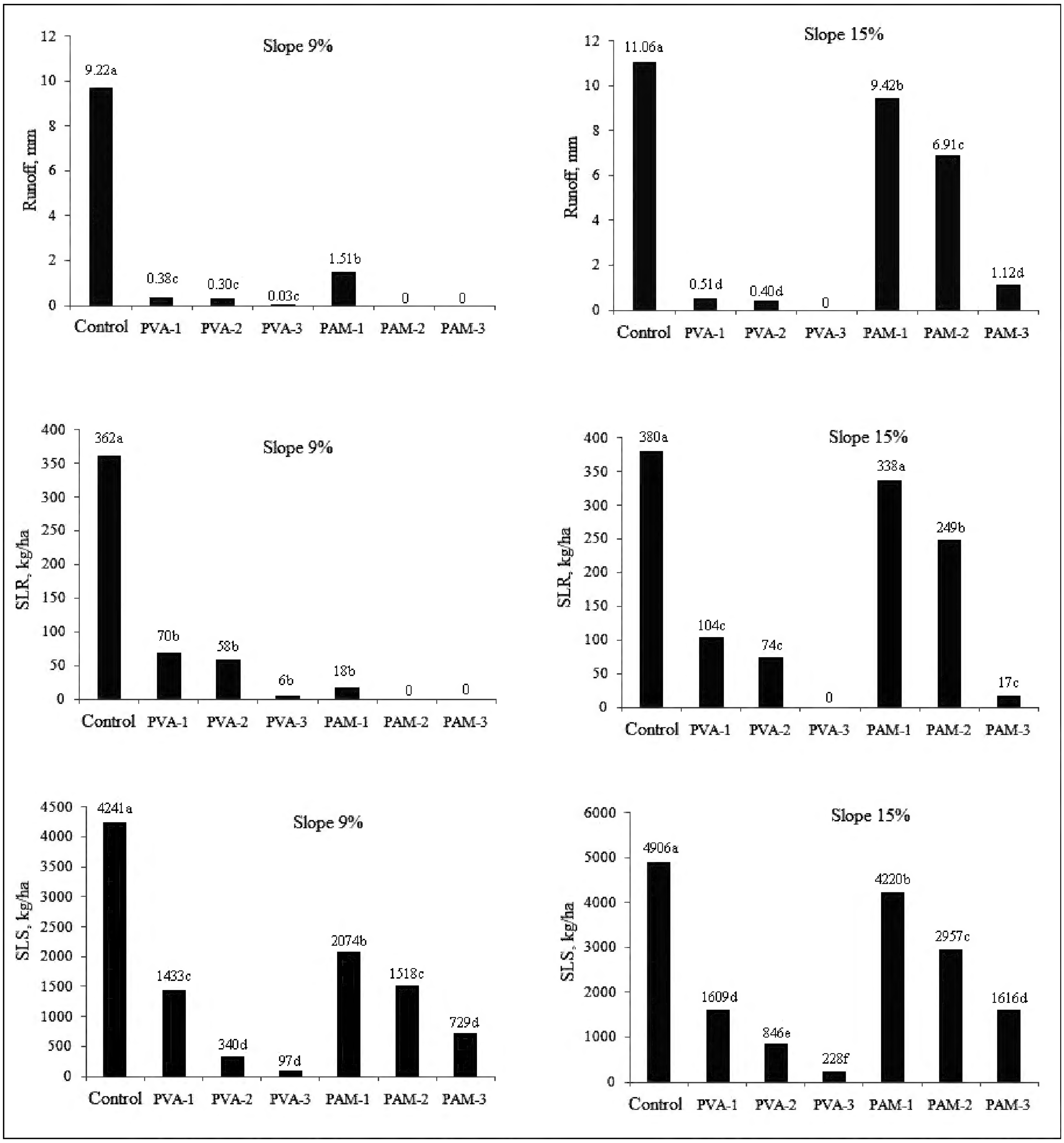

Figure 3. Changes in soil and water losses in two slope angles (SLR: soil loss by runoff, SLS: soil loss by splash)

Results

The comparison of the effects of treatments on runoff, soil loss by runoff (SLR) and soil loss by splash (SLS) values of Chromic Haplustert soil is given in Figure 3. According to Figure 3, the highest runoff occurred from the control pan (9.22a) in Vertisol soil at 9% slope, followed by PAM1 (1.51b) treatment. There was no statistical difference between the PVA application doses in terms of their effects on runoff, on the other hand, no runoff occurred after 1 hour of simulated rainfall in the pans with

high PAM doses. Among the pans at 15% slope, the highest runoff occurred in the control pan (11.06a), followed by PAM1 (9.42b) and PAM2 (6.91c) treatments. It was also concluded that no runoff occurred from the pan treated with PVA3 and the lowest runoff values were obtained with PVA1 (0.51d), PVA2 (0.40d) and PAM3 (1.12d) treatments, which were not statistically different.

According to Figure 3, it was observed that the highest SLR occurred in the control pan (362a) at 9% slope. At this slope, the effect of all PVA treatments and PAM1 treatment on SLR was statistically the same. No surface runoff occurred at the end of 1 hour of simulated rainfall in the pans where PAM2 and PAM3 treatments were applied. When the data for the pans with 15% slope are examined, it is seen that the highest SLR occurred in the control (380a) and PAM1-treated pan (338a), which are statistically similar. If the pan with PVA3 treatment, which did not have SLR at the end of the raining period, is excluded, the least SLR occurred in the pans with PAM3 (17c), PVA1 (104c) and PVA2 (74c) treatments, which were statistically similar.

When the bar graphs of the comparison of SLS data at 9% slope are examined (Figure 3), it is seen that the highest SLS was formed from the control pan (4241a). PVA1 (1433c) and PAM2 (1518c) treatments did not show statistical difference in terms of their effects on SLS. The lowest SLS values were recorded for the statistically identical PVA3 (97d), PVA2 (340d) and PAM3 (729d) treatment pans. In Chromic Haplustert soil on a high slope, the highest SLS occurred in the control pan (4906a), followed by the pans with lower PAM doses. The effects of the highest PAM dose and the lowest PVA dose on SLS were the same in Vertisol soil at 15% slope. The lowest SLS occurred in the PVA3 treatment pan (228f).

Discussion

When the total soil-water losses occurring at different slopes from Chromic Haplustert are compared, it is noteworthy that the losses occurring at 15% slope are numerically larger than the losses occurring at 9% slope. This may be due to the increase in runoff velocity and erosion power with increasing slope grade. The increased runoff velocity may have also increased the flow rate of the runoff, thus increasing the total amount of runoff generated in a 1-hour period. Brown et al. (1989) explained that an increase in runoff flow rate increases rill erosion. On the other hand, increasing slope angle increases the kinetic energy of the runoff. As the kinetic energy of the runoff increases, it gains the power to drag larger particles and erodes more soil, thus creating more material to be transported in suspension. Runoff velocity, flow rate and kinetic energy are runoff components that directly affect the amount of soil transported (Özdemir, 2002) and they are always evaluated as main or sub-factors in the developed water erosion prediction models.

According to the findings of the experiment, the total soil loss by runoff at 9% slope is a fraction of the loss by splash at the same slope. Similarly, the soil loss by splash at 15% slope is many times more than the amount of soil transported in sus-

pension by runoff. This result is most likely due to the fact that the energy of a raindrop is about 260 times that of runoff (Hudson, 1995) and that splash transport begins immediately upon contact with bare soil surfaces. In a study (Karaoğlu and Çanga, 2002) conducted by utilizing simulated rainfall under laboratory conditions, it was stated that a soil may give different values of surface runoff and soil loss at different slope levels. Changes in the degree of slope cause the infiltration properties of soils to be different and this situation can strongly affect the properties of the runoff that will occur on the surface of the soils. Differences in the characteristics of surface runoff also change the amount of soil transported.

Soil aggregates are stabilized by both macroscopic and microscopic forces. Macroscopic forces include biotic components such as plant roots and fungal hyphae, cementing agents such as $CaCO_3$ and sesquioxides, and organic polyelectrolytes. Microscopic forces are electrostatic attractions and Van Der Waals bonds (Greenland, 1979). Considering the 73% clay content in the surface horizon of the Vertisol subject to this study, it can be said that it has durable aggregates in terms of macro-micro forces. The effectiveness of the polymers may have been complicated because the precipitation with an intensity of 70 ± 5 mm h^{-1} and a kinetic energy of approximately 27.95 J m^{-2}-mm, which was rained for one hour, was probably not strong enough to break down the aggregates of the polymer-treated Vertisol soil. If the duration or intensity of the rainfall had been extended or increased, perhaps the effect of the high molecular weight PAM polymer would have been seen more clearly. On the other hand, in some high dose polymer applications in Chromic Haplustert soil, surface runoff and soil loss values at the end of the rainfall period could not be recorded and were used as "zero" in the calculations. This may have resulted in the complexity of the effect of the polymers in this soil.

The protective effect of soil-applied polymers on the durability of the structural structure depends on their adsorption on the outer surfaces of the aggregates as well as on the amount of clay fraction and type of clay mineral. In Vertisol soil with 73% clay content, the effects of PAM and PVA may have been complicated because the application doses were high. In other words, since both of the polymers used in this study are anionic, the effect of polymers on soil water losses in Vertisol, which is rich in clay fraction, which is already a source of anionic charge, may have been complex. It may be a more appropriate way to investigate the effects of polymers in this soil with lower dose applications. Many researchers (Miller et al. 1998; Peterson et al. 2002; Kukal et al. 2007) have concluded that polymers can reduce the total soil-water losses under simulated rainfall using various polymers.

Conclusions

It is known that anionic polymers have positive effects on soil physical properties. They decrease soil and water losses by preserving the aggregate stability property of soils. Otherwise, their effectiveness changes depending on application dose, landscape

elements (slope etc.) and soil physicochemical and morphological properties. Key findings of this study are: (i) as a result of high dose polymer applications in this Vertisol, runoff and associated soil loss did not occur at the end of the rainfall simulation period, (ii) considering the total runoff and soil losses occurring at different slopes, it was determined that the losses occurring at a 15% slope were higher than the losses occurring at a 9% slope, (iii) in general, PVA is more effective than PAM in terms of decreasing soil/water losses, (iv) with increasing dosage applications of polymers, the start time of runoff was delayed during rainfall simulation period, and at the end of the rain total soil/water losses decreased, (v) for decreasing soil and water losses, the most effective dose is PVA-3 treatment (14 kg ha^{-1}). Also PVA-2 (7 kg ha^{-1}) and PVA-1 (3.5 kg ha-1) can be selected by considering economical conditions. But, high dosage PAM should be preferred because, especially on the high slopes, its low dosage doesn't work. For more meaningful results, management practices that integrate polymer applications should be improved. Polymers should be subjected to trials in soils under different uses, for example, forest, agriculture, burnt forest, etc.

Acknowledgements

This work has been financially supported by Ondokuz Mayis University Scientific Research Projects Department (Project number: BAP-Z501). This paper is based on a part of the Ph.D. thesis of the first author, Tugrul Yakupoglu. The second author Nutullah Ozdemir is the supervisor of that Ph.D. thesis. This study was previously presented as oral at the VI. International Anatolian Agriculture, Food, Environment and Biology Congress- TARGID-2022 and published only as an abstract.

References

Aksakal E.L., Öztaş, T. 2004a. Effect of Polyvinylalcohol (PVA) on Reducing Soil Compactibility as an Indication of Hydraulic Conductivity. International Soil Congress (ISC) on Natural Resource Management for Sustainable Development, June 7-10, Erzurum, Türkiye. CD of Proceeding of the International Soil Congress, proceeding code: A8.

Aksakal E.L., Öztaş, T. 2004b. Maximum Dry-bulk Density and Optimum Moisture Content Relations in Soils Treated with PVA. International Soil Congress (ISC) on Natural Resource Management for Sustainable Development, June 7-10, Erzurum, Türkiye. CD of Proceeding of the International Soil Congress, proceeding code: A10.

Aslan N. 2004. Effects of Cross-Linked Polyacrylamides with Polivinil Alcohol on Soil Structural Properties, Soil Water Characteristics and Plant (*Zea* Mays and *Phaseolus Vulgaris* L.) Biomass, Ph.D. Thesis Atatürk University, Institute of Natural and Applied Science, Erzurum, Türkiye, 82p.

Brown L.C., Foster G.R., Beasley D.B. 1989. Rill Erosion as Affected by Incorporated Crop Residue and Seasonal Consolidation. Transactions of the ASAE 32, 1967-1978.

Doğan O., Özel M.E. Yıldırım H., Küçükçakar, N. 2000. Erosion Risk Mapping of Dalaman Basin Located in Mediterranean Region Using CORINE Method. Proceedings of Interna-

tional Symposium on Desertification (ISD), June 13-17, Konya, Türkiye, Congress Book, 125-128.
Erpul G., Çanga, M.R. 2001. Design Principles of a Rainfall Simulator and Characteristics of Simulated Rainfalls for Soil Erosion Studies. Journal of Agricultural Sciences 7, 75-83.
Evin G., Erpul G., Bayramin İ., Kibar B. 2004. Establishment of Erosion Measures as A Part of the Site-Specific Special Area Reinstatement Plan of Baku-Tbilisi-Ceyhan Crude Oil Pipeline Project-Lot B. International Soil Congress (ISC) on Natural Resource Management for Sustainable Development, June 7-10, Erzurum, Türkiye.Congress Abstract Book, 30.
Green V.S., Stott D.E., Norton L.D., Graveel J.G. 2000. Polyacrylamide Molecular Weight and Charge Effects on Infiltration under Simulated Rainfall. Soil Sci. Soc. Am. J. 64, 1786-1791.
Greenland, D.J., 1979. Structural Organization of Soils and Crop Production. Soil Physical Properties and Crop Production in the Tropics (EDS.: R. Lal, D.J. Greenland). NY, John Willey, 47-56.
Kara E.E., Apan M., Korkmaz A., Gülser C., Kara T. 1993. Survey and Mapping of the Soils of Ondokuz Mayis University Settlement Area and Determination of Some Properties in terms of Irrigation. Ondokuz Mayis University Research Project Final Report, No: Z-073, Samsun, Türkiye.
Karaoğlu M., Çanga M.R. 2002. The Consecutive Simulated Rainfall, Slope and Phosphogypsum's Effects on Runoff and Erosion. International Conference on Sustainable Land Use Management. Sharing Experiences for Sustainable Use of Natural Sources. June 10-13, Çanakkale, Türkiye. Proceeding Book, 282-289.
Kinnell P.I.A., 2005. Raindrop-impact-induced Erosion Processes and Prediction: A Review. Hyrological Processes 19, 2815-2844.
Köse C., Taysun, A. 2000. Determining of P Factor for Contour Tillage Using Rainfall Simulator under Field Condition in Aegean Region. International Symposium on Desertification, June 13-17, Konya, Türkiye. Proceedings Book, 139-142.
Kukal S.S., Kaur M., Bawa S.S., Gupta N. 2007. Water-drop Stability of PVA-treated Natural Soil Aggregates from Different Land Uses. Catena 70, 475-479.
Miller W.P., Willis R.L., Levy G.J. 1998. Aggregate Stabilization in Kaolinitic Soils by Low Rates of Anionic Polyacrylamide. Soil Use and Management 14, 101-105.
Moore C.D., Singer M.J. 1990. Crust Formation Effects on Soil Erosion Processes. Soil Sci. Am. J. 54, 1117-1123.
Nearing M.A., Bradford J.M., Holtz R.D. 1986. Measurement of Force vs. Time Relationship for Waterdrop Impact. Soil Sci. Soc. Am. J. 50, 1532-1536.
Özdemir N. 2002. Soil & Water Conservation. Ondokuz Mayis University Faculty of Agriculture Pulications, No: 22, Samsun, Türkiye.
Özen F. 1988. A Phytosociological Research on the Vegetation of Ondokuz Mayıs University Kurupelit Campus Area and its Surroundings. Ondokuz Mayis University Institute of Science and Technology, M.Sc. Thesis. Samsun, Türkiye.
Peterson J.R., Flanagan D.C., Tishmack J.K. 2002. PAM Application Method and Electrolyte Source Effects on Plot-scale Runoff and Erosion. ASAE 45, 1859-1867.
Şahin K., Alagöz Z. 2000. The Determination of Relationships between Physical Properties on Some Great Soil Groups in The Antalya Region and Water Erosion under Simulated Rainfall. Symposium on Desertification, June 13-17, Konya, Türkiye. Proceedings Book, 52-56.
Sharma P.P., Gupta S.C., Rawis W.J. 1991. Soil Detachment Caused by Rainfall. Soil Sci. Soc. Am. J. 55, 301-307.
Sojka R.E., Lentz R.D., Westermann D.T. 1998. Water and Erosion Management with Multiple Application of Polyacrylamide in Furrow Irrigation. Soil Sci. Soc. Am. J. 62, 1672-1680.

Yakupoglu T. 2010. Determining Water Erosion Sensitivity of Soils in Minoz and Golet Catchments in Samsun City under Loboratory Conditions. Ondokuz Mayis University Institute of Science and Technology, Ph.D. Thesis. Samsun, Türkiye.

Yakupoglu T., Ozdemir N., Ekberli I., Oztürk E. 2018. A Modified Rainfall Simulator: Design Principles, Rainfall Characteristics and Simulation Ability to Natural Rains. Fresenius Environmental Bulletin 27, 2834-2843.

Yolcu G. 2001. The Effect of Some Polymers on Runoff and Soil Loss together with Soil Properties in Laboratory Conditions. Ph.D. Thesis, Ege University, Institution of Natural and Applied Science, İzmir, Türkiye 128p.

Yönter G., Geren H., 2006. Pre-investigations on the Effect of Soil Erosion by Water of Different Pasture Mixtures under Laboratory Conditions. Journal of Ege University Faculty of Agriculture 43, 121-131.